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A STATISTICAL ANALYSIS OF WESTERN NORTH PACIFIC OCEAN TROPICAL CYCLONE DANGER AREA FORECASTS

by

Terry Dean Snow

September 1980

Thesis Advisor: W. van der Bijl

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A Statistical Analysis of Western North Pacific Ocean Tropical Cyclone Danger Area Forecasts

by

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Lieutenant, United States Navy
B.S., University of Washington, 1972

Submitted in partial fulfillment of the requirements for the degree of

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from the

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September 1980

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ABSTRACT

This study investigates 24-hour forecasts of 30-kt wind danger areas for western North Pacific Ocean tropical cyclones. The forecasts for 1979 have been verified against the 30-kt wind areas observed over a period of 24 hours. The threat scores of these verifications have been statistically analyzed. The dependency of threat scores on the five parameters: (a) speed of movement, (b) maximum observed wind, (c) direction of movement, (d) latitude and (e) longitude, was found to exist at the 1% level of significance.

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I. INTRODUCTION

The tropical cyclone is an operational threat to U.S. forces throughout the world, whether they be Navy, Air Force, or other DoD activities. This threat is dealt with more frequently in the western North Pacific Ocean area because it is this area that spawns an average of 30 tropical cyclones annually. Afloat units of the Seventh Fleet in the western North Pacific routinely calculate the 24-hr 30-kt danger area of tropical cyclones in order to determine actions required for evasion or the seeking of a protective port haven.

In 1977, Commander Amphibious Force Seventh Fleet submitted an operational requirement for an improved method of forecasting and/or calculating the danger area of tropical cyclones. The inadequacy of the present method in meeting the requirement to maintain a high state of readiness while keeping evasion costs to a minimum led to this request.

In order to develop another method for defining the dangerous area of tropical cyclones to be avoided by operational units, the performance of the present method must be analyzed. This analysis will provide information useful in the development of improved danger area forecasting methods.

To gauge how well the present method is depicting the 24-hr 30-kt danger area, the following steps were taken:

1. Assembled and consolidated the data intc a usable format.

2. Determined threat score values for each forecast.

3. Performed a variance analysis on the threat scores based on five storm parameters at forecast time, namely wind speed, direction of movement, speed of movement, latitude and longitude.

From the results of the analysis, a determination of the accuracy of the present method was made. Based on this determination, recommendations for continued testing of the present method and possible improved methods of forecasting the danger area were made.

II. DESCRIPTION OF THE DATA

The Naval Environmental Prediction Research Facility, Monterey, California (NEPRF) provided western North Pacific tropical cyclone forecasts from the Joint Typhoon Warning Center, Guam (JTWC) for 1979. The data were formated to provide all the information available on a typical JTWC forecast. The total number of warnings coded in the data format was 647. The data extracted for use in this research included the initial and 24-hr positions along with their respective 30-kt wind radii, the maximum wind speed, direction of movement and speed of movement at forecast time.

The 30-kt wind radii were coded in such a way to allow a high degree of flexibility in defining the area of 30-kt winds. In order to define the asymmetrical characteristics of most storms, extended radii were assigned to quadrants or semi-circle sectors along one of eight radial directions. The radii were in tens of nautical miles (n mi). Figure 1 shows three examples of typical 30-kt wind radii patterns, along with their respective code.

In the process of determining the 30-kt danger area, the data were checked for errors and corrected when necessary using the NOCC/JTWC Annual Typhoon Report (1979). Rarely were the data uncorrectable and therefore unusable in the calculation of the danger area and its subsequent verification

area. Each 24-hr 30-kt danger area to be verified required position and wind radii information for the four subsequent 6-hourly positions of the storm, therefore storms with missing data or storms in the dissipation stage were not verified. Also, warnings that did not forecast 30-kt winds at the 24-hr position were not verified. Table I presents a listing of storms and their respective warning numbers that were verified and statistically analyzed.

III. THREAT SCORE DETERMINATION

As a measure of the accuracy of the 24-hr danger area forecasts, the verification score method called threat score was used. Appendix A provides the details of this calculation. Figure 2 is an example of two 24-hr 30-kt danger area plots and their respective verification areas for Tropical Cyclone Alice with the specific areas used in determining a threat score depicted. The threat score value represents the ratio of the 30-kt area forecast correctly (area A) to the total of the 30-kt forecast area (areas A and B) and the area where 30-kt winds were observed but not forecast (area C). An increase in areas forecast incorrectly (B and C) causes the threat score to be lower, indicating that the forecast has lower skill.

To determine threat score values, the danger area and the verification area were transferred to a 60 x 60 x-y coordinate grid with 30 nautical mile spacing to allow computer calculation. The grid dimensions chosen provided the best trade-off between errors in area and the computer time required to produce the grid field of 30-kt wind values. Each grid point represents 900 square nautical miles of area and due to the nature of the grid overestimates the true 30-kt areas by approximately 3%.

To calculate the forecast danger area, the following steps were taken:

1. Assigned 30-kt radii plus an additional 135 n mi to the eight radial directions of the forecast center. 135 n mi was added because it is a measure of the average 24-hr positional error in the forecast, and follows present guidance for determination of the 30-kt danger area. The addition of this 135 n mi created a built-in forecast bias since it has a greater effect on the danger area of small radius storms than on large radius storms (e.g. the addition of 135 n mi to a 100 n mi radius storm increases its area by 5.5 times whereas 135 n mi added to a 200 n mi radius storm increases its area by 2.8 times).

2. Assigned 30-kt radii to eight radial directions about the initial warning position.

3. Determined rate of growth of 30-kt wind radii per radial direction for three-hourly time steps. Three-hourly time steps were chosen to improve computer compilation speed without generating an unwanted amount of error in the area determination.

4. Determined change in latitude and longitude for three-hourly time steps from 24-hr warning position to initial warning position.

5. Starting from the 24-hr position,with its respective radii,determined if each grid location was inside or outside the 30-kt wind radius.

6. Assigned each grid location a wind speed value based on this linear relationship:

$$\text{Field}_{m,n} = 30(2-{}^{D}/CD),$$

where CD is the 30-kt radius assigned in the direction of that specific grid point, and D is the distance from the position of the storm to the grid point. Therefore, every point inside the 30-kt radius was assigned a value greater than 30.

7. Steps 5 through 6 were repeated for each time step allowing the storm to move while the 30-kt radii changed at the rate of growth found in step 3. This enabled the total forecast 30-kt area to be transferred to a grid point representation.

To calculate the verification grid, steps similar to the danger area calculation were performed, the major difference being the use of the present warning and the four subsequent 6-hourly warning positions and their 30-kt radii to define the actual 30-kt wind area for the 24-hr period.

Once the danger area grid was found, its respective verification grid was used in comparing grid values to determine which category of the threat score contingency table applied. Then from these three categories, a threat score for each warning was found. Figure 3 is an example of the computer generated 30-kt danger and verification areas with the threat score area categories depicted for the same warnings as Figure 2.

IV. STATISTICAL STUDY USING ANALYSIS OF VARIANCE TECHNIQUE

A. ANALYSIS OF VARIANCE

The relationship between two variables (e.g. sunspots and annual air temperatures) can be investigated as follows: categorize each year according to high, medium and low sunspot numbers; then find the average air temperature for each of the three groups. If the three averages are nearly identical, there is clearly no evidence of sunspot influence. On the other hand, if the three group averages differ by, say, 10°C, there is clearly a sunspot influence. But if the difference between the three groups are only a few degrees or parts of a degree a difficult situation arises. Can that small difference be interpreted as a sunspot influence, or could it possibly be a "spill over" effect of the individual random differences from year to year? The analysis of variance technique tries to bring in some probabilistic arguments to determine if there is an influence or not.

The basis of the method is the testing of the equality of estimated variances. It is assumed that these estimates have independent χ^2 - distributions for their respective degrees of freedom. It can be proved that the ratio of these estimates follows the F-distribution. Therefore, the F-distribution can be used to determine if the estimated variance between groups is large enough to imply that the

systematic effect (i.e. between groups) is greater than the random or residual variablility.

B. APPLICATION OF ANALYSIS OF VARIANCE ON THREAT SCORES

A study on tropical cyclone position errors by Nicklin (1977) determined that certain parameters associated with a tropical cyclone accounted for the greatest amount of explained variance. Based on this study, the analysis of variance technqiue was used to determine if the following parameters significantly influence the threat scores: maximum wind speed, direction of movement, speed of movement, latitude and longitude of the storm.

For reasons of simplicity, a one-way analysis of variance (AoV) was performed first on these five parameters. Then for comparison, a five-way AoV was performed on the same five parameters. To determine the effects of the influential parameters, each parameter was separated into subgroups, for the AoV testing. Wind speed was divided into three groups, one with wind speeds less than or equal to 35 kt, one with wind speeds greater than 35 kt but less than or equal to 65 kt, and the other with wind speeds greater than 65 kt. These three groups correspond closely to the three classes of the tropical cyclone: depression, storm and typhoon. The direction of movement parameter was divided into a group of primarily westward moving storms, with movement directions of STA (stationary), S, SSW, SW, WSW, W, WNW and NW;and another group of primarily northward and eastward moving storms.

with movement directions covered by the remaining directions NNW, N, NNE, NE, ENE, E, ESE, SE and SSE. The following is a listing of forecasts in each group for each directional band:

WESTWARD GROUP

S	SSW	SW	WSW	W	WNW	NW	STA
3	1	3	5	98	154	93	17

NORTHWARD AND EASTWARD GROUP

NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
31	49	18	25	3	2	1	1	0

Speed of movement was divided into three groups, the first with movement speeds less than or equal to 6 kt, the second with speeds greater than 6 kt but less than or equal to 13 kt, and the last group with speeds greater than 13 kt. Latitude was separated into two groups, one with latitudes less than or equal to 20° N and one in which the storms were north of 20°N. Finally, longitude was separated into two groups, the first in which the storms were west 130° E and the other in which the storms were either at 130° E or east of 130° E.

The theoretical development of the one-way AoV is presented in Appendix B. The same basic theory also applies to the five-way AoV.

V. RESULTS

The results of the AoV testing show the strength of each parameter's influence on the threat score values. The presence of an influence was statistically established if the calculated F-value of that parameter was significantly larger than 1 for its respective degrees of freedom. This determination is made by comparing the computed F-value to a theoretical F-value for 5% and 1% levels of significance, where the 1% level is more significant. Also, the larger the difference between the calculated F-value and the theoretical F-value, the greater the influence of that parameter on the threat scores. If the F-value of a parameter is less than the theoretical value, it must be assumed that the parameter did not have any influence on the threat scores, or that the influence was so small that the size of the investigation sample was not large enough to decipher the weak influence. The theoretical F-value can be found in any mathematical handbook using the respective degrees of freedom of the numerator and denominator of the variance ratio.

Table II provides the basic statistics (giving mean, variance and standard deviation) for the total sample of 506 threat score values. The mean value can be used to obtain a feel for how the threat scores were affected by a specific parameter subdivision by comparing the overall mean to the subdivision means.

Tables III thru VII show the results of the one-way AoV for each of the five parameters. Table VIII shows the results of the five-way AoV on all five parameters combined. The results of the five-way AoV are more significant because all five group influences are subtracted from the overall fluctuations, thereby reducing (in this case substantially) the mean square of the residual, which in turn increases the F-value.

The calculated F-values indicate that each parameter did influence significantly the threat score values, with the greatest influence being caused by the intensity of the storm (maximum wind speed) and the least by its speed of movement. Figure 4 is the frequency distribution of threat score values for all warnings and should be used in comparing the distributions of threat scores for each parameter's subdivisions.

The largest significant influence is that due to wind speed ($F_{calc} = 249.27$ vs $F_{table} = 4.65$ at 1%). This is corroborated by Figure 5 which shows that weak storms have rather low threat scores and the more intense storms (> 65 kt) relatively high threat scores. This implies that for initial depressions the danger area is either overforecast (the storm didn't intensify as expected and the 135 n mi addition to the 24-hr radius caused the danger area to be too large) or the observed 30-kt area was mainly outside the forecast area (the latter error being caused by a storm having large

positional error in a direction other than that forecast). Threat scores are very high for maximum wind speeds greater than 65 kt and exhibit a subdivision mean threat score of 0.566 with a number of cases with threat scores above 0.700. This indicates that well developed systems are better forecast because of more accurate center locations (both forecast and initial), greater areal development of the 30-kt wind field and the fact that the 135 n mi radius addition has a smaller effect on the total danger area for larger radius storms.

The direction of movement and latitude parameters (Figures 6 and 7) have similar frequency distributions which means that most northward and eastward moving storms are north of 20°N. The influence of these two parameters is such that storms north of 20°N and in the northward and eastward moving group were forecast above average while those at 20°N or southward and moving in a generally westward direction were forecast near the mean threat score for the total sample. This influence was probably mainly due to the built-in bias of the 135 n mi addition because storms that were northward and eastward moving have larger 30-kt radii than lower latitude storms that were just developing and westward moving.

Longitude subdivisions (Figure 8) indicate that the storms west of 130°E have higher threat scores than those at 130°E or eastward. This effect can be attributed to the fact that storms west of 130°E are well developed, have well-

defined track histories and are larger than storms at 130°E or eastward (again pointing to the size bias).

The computed F-value of the speed of movement parameter is 3.31 in the one-way AoV where as the F-table indicates that an F larger than 3.01 is required for a 5% level of significance. For the five-way AoV, the F_{calc} is 9.20 vs 3.01 in the table. Therefore, the speed of movement parameter (Figure 9) is barely significant in the one-way test, but improved its significance in the more decisive five-way test. The only speed of movement subdivision that indicates any marked change from the overall mean threat score is the group that was moving at speeds greater than 13 kt. This higher threat score is due to faster storms being better developed and having positional errors along the direction of motion, and the size bias since the faster storms as a group generally have larger radii than the slower storms.

VI. CONCLUSIONS

The purpose of this study was to determine the accuracy of the present method of calculating the 24-hr 30-kt danger area of tropical cyclones. In the process of this determination, the effect of five storm parameters on the accuracy of the method was examined.

In analyzing the influence of the five parameters, it was determined that the five parameters did, in varying degrees, affect the threat score results. However, because of the built-in size bias, created by the addition of 135 n mi to the 30-kt radii of the 24-hr forecast, the strength of the physical reasons behind the various subdivision influences on the threat scores is masked.

From examining the threat score results, it can be concluded that the present method forecasts too much area that does not verify as a dangerous area (area B) and/or that the area where 30-kt winds were observed but not forecast was a major factor (area C) and thereby kept the average threat score below 0.50. A review of the contingency values that make up the threat score values indicates that the former was the case, and because of this overforecasting, area C was usually quite small.

Therefore, it can be concluded that the present method does quite well in meeting the objective to keep all afloat units well warned of the dangerous area, but the overforecasting

(area B) may have caused some unnecessary evasions. In today's era of high fuel costs, evasions are quite costly. Thus there is definitely a need for the danger area method to be modified in such a way as to keep the overforecast area (area B) to a minimum. It is realized that further work needs to be done on improving the method if the requirements of the Commander Amphibious Forces Seventh Fleet are to be met.

VII. RECOMMENDATIONS

This study determined that the present method of calculating the 24-hr 30-kt danger area overforecasts the danger area, but by doing so kept the underforecasting to a minimum (area C). It also determined that the straight addition of 135 n mi to the 24-hr 30-kt forecast radii created a size bias that caused smaller radii storms to be overforecast more than larger radii storms. Although not brought out in this study previously, the present danger area calculation method doesn't provide the user a method to gauge the relative probability of being in a dangerous situation. The threat score also doesn't present the user the means to distinguish the likelihood of one area of the danger area verifying more often than another.

To obtain a feel for the size bias effect on the threat scores a few threat scores were recalculated without the 135 n mi addition. It was found that this improved the threat scores by nearly +0.20 on the average with some improvements as high as +0.40. This gain in skill was obtained by a significant decrease in the size of the area that was forecast but not observed (especially for smaller storms) but this gain was not made without a slight increase in the area where 30-kt winds were observed and not forecast (area C). The above test means that the 135 n mi addition that is now made as a means of covering the average 24-hr error of JTWC's

warnings should not be applied in its present form. To further improve the skill of the danger area forecast it is recommended that a warning error factor be applied based on size of the storm and that further testing be done to determine the effect on danger area accuracy.

To gauge the probability of being in a dangerous situation, NEPRF is testing the feasibility of probability type forecasting in their Strike-P and Wind-P programs. Although much more flexible than the present method of danger area determination, these methods will need to be tested to determine how the probability values correspond to an area that must be avoided at all costs.

Another way to develop a new danger area determination would be to composite the 30-kt verification grid points in forecast warning coordinates. This technique would be very similar to that used by Gray and Frank (1978) and would provide a way to assign a value of danger to a particular area around a 24-hr forecast storm position.

The goal of studying how well the present method of determining the dangerous area of tropical cylones has been met. Some ideas for future research in danger area development have been brought to light. It is hoped that future efforts and development will meet Fleet user desires.

APPENDIX A

Threat Score Calculation Formulae

From a contingency table and associated information the Threat Score (TS) can be calculated:

		EVENT ESTIMATED YES	EVENT ESTIMATED NO	
EVENT OBSERVED	YES	A	C	Total (T) = A + B + C + D
	NO	B	D	No. of Correct Forecast (FC) = A + D

$$TS = \frac{A}{T - D} = \frac{A}{A+B+C}$$

Range: $0 \leq TS \leq 1$

TS score values indicate more skill with larger positive values.

APPENDIX B

One-Way Analysis of Variance Theory

The following are the basic mathematical variables and equations used in the one-way AoV:

X_{ij} = threat score of each 30-kt danger area forecast,

μ = the unknown population mean,

$X_{ij} = \mu + G_i + E_{ij}$.

G_i are the unknown group influences for their respective groups, where i takes on values representing the subdivisions of each parameter. The true average of subgroup i can be thought of as the sum of the true population mean μ and the unknown group influence, G_i. Therefore, G_i may also be seen as the true systematic deviation. E_{ij} is the true residual influence which includes the errors in true determination of the threat score. It can be thought of as the true random deviation.

From simple algebra, one finds that the true total deviation $X_{ij} - \mu$ can be divided into the true systematic deviations, G_i, plus the true residual deviation, or:

$$X_{ij} - \mu = G_i + E_{ij} \qquad (1)$$

Since the population mean, μ, the true systematic deviation, G_i, and the true residual deviation, E_{ij}, are unknown, they must be estimated.

$$X_{..} = \frac{1}{n} \sum_{i=1}^{3} \sum_{j=1}^{n_i} X_{ij} \text{ with } \sum_{i=1}^{3} n_i = n$$

is the sample mean and an estimate of μ for the case where there are three subdivisions. Therefore, $X_{ij} - X_{..}$ is an estimate of $X_{ij} - \mu$, but also of $G_i + E_{ij}$ (see eq. 1). The difference $X_{ij} - X_{..}$ is denoted as x_{ij} and called the total deviation. The computed average of an individual group is

$$\frac{1}{n_i} \sum_{j=1}^{n_i} X_{ij} = X_{i.}$$

The computed group deviations, $X_{i.} - X_{..}$, are the estimates for G_i which will be called g_i. Then the total deviation minus the group deviation or $x_{ij} - g_i$ is an estimate of E_{ij} and becomes the computed residual deviation, e_{ij}.

It is assumed that the true random deviations, E_{ij}, are normally distributed with a mean of 0 and variance σ^2. The n values of e_{ij} can be computed and is usually called the mean square of the residual ($MS_{residual}$). This variance is found from the following equation:

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^{3} \sum_{j=1}^{n_i} (X_{ij} - X_{i.})^2}{n - 3} . \qquad (2)$$

Since x_{ij}, was an estimate of $X_{ij} - \mu$ an individual group deviation can be written as

$$g_i = \frac{1}{n_i} \sum_{j=1}^{n_i} x_{ij} = \frac{1}{n_i} \sum_{j=1}^{n_i} (X_{ij} - X_{..}),$$

which is an estimate of

$$\frac{1}{n_i} \sum_{j=1}^{n_i} (X_{ij} - \mu) = \frac{1}{n_i} \sum_{j=1}^{n_i} (G_i + E_{ij}) = G_i + E_{i.},$$

with $E_{i.}$ being the average of n_i values of E_{ij}.

It follows then, that the variance of g_i is an estimate of the variance of $G_i + E_{i.}$. The variance of a sum is the sum of the variances if the variables are independent of each other. Since the random error E_{ij} (and therefore also $E_{i.}$) is independent of the systematic influence G_i the following holds:

$$\text{Var } (G_i + E_{i.}) = \text{Var } G_i + \text{Var } E_{i.} = \sigma_G{}^2 + \frac{\sigma^2}{n_i},$$

where $\sigma_G{}^2$ is the variance between true group deviations. $\text{Var } E_{i.} = \text{Var } E_{ij}/n_i$ where $E_{i.}$ is the average of n_i values of E_{ij} and $\text{Var } E_{ij} = \sigma^2$. It follows from these theoretical statements that the variance of g_i is an estimate of $\sigma_G{}^2 + \frac{\sigma^2}{n_i}$. Multiply the statement in the preceding sentence by n_i, resulting in n_i times the variance of g_i being an estimate of $n_i\sigma_G{}^2 + \sigma^2$. Now n_i times the variance of g_i is called the mean square (MS) of the systematic deviations. This variance estimate or $\text{MS}_{\text{systematic}}$ is given by

$$n_i\hat{\sigma}_G^2 + \hat{\sigma}^2 = \frac{1}{3-1}\sum_{i=1}^{3} n_i(X_{i.} - X_{..})^2. \tag{3}$$

By forming a ratio of the variance estimates given by equations (3) and (2), the systematic effect on the variance can be measured. The ratio is called the variance ratio and is given by

$$F = \frac{\frac{1}{3-1}\sum_{i=1}^{3} n_i\,(X_{i.} - X_{..})^2}{\frac{\sum_{i=1}^{3}\sum_{j=1}^{n_i}(X_{ij} - X_{i.})^2}{n-3}} \tag{4}$$

If the F-value is near 1, it is assumed that $n_i \sigma_G^2$ is zero or very small and that the observed group variance is just due to chance fluctuations and can't be attributed to a systematic influence. When the F-value is significantly larger than 1 as determined by an F-table, the null hypothesis: $\sigma_G^2 = 0$ must be rejected and the alternate hypothesis $\sigma_G^2 \neq 0$ must be accepted,which means that there is enough statistical evidence for a systematic influence by that particular parameter.

TABLE I: WARNINGS VERIFIED AND STATISTICALLY ANALYZED FOR 1979

CYCLONE NUMBER	CYCLONE NAME	WARNING NUMBER
1	Alice	1-47
2	Bess	1-17
3	Cecil	5-36
4	Dot	2, 8-20
5	TD 5	NONE
6	Ellis	1-18
7	Faye	1-15
8	TD 8	NONE
9	Hope	1-6, 9-11, 17-29
10	Gordon	1-9
11	TD 11	NONE
12	Irving	1-34
13	Judy	1-34
14	TD 14	NONE
15	Ken	1-9
16	Lola	1-19
17	Mac	1-17
18	Nancy	1-5
19	Owen	1-33
20	Pamela	1-2
21	Roger	1-12
22	Sarah	1-3, 9-29, 35-39
23	Tip	1-56
24	Vera	1-19
25	Wayne	1-13, 16-17
26	TD 26	NONE
27	Abby	1-27, 34-45
28	Ben	1-6
	TOTAL WARNINGS	506

TABLE II: BASIC STATISTICS FOR 506 VALUES OF THREAT SCORE

MEAN	VARIANCE	STANDARD DEVIATION
0.414	0.044	0.209

TABLE III: ONE-WAY AOV STATISTICS FOR WIND SPEED

	WS≤35KT	35KT <WS65≤KT	WS>65KT
MEAN	0.173	0.389	0.566
VARIANCE	0.030	0.021	0.019
STD. DEV.	0.172	0.146	0.136
NUMBER IN SUBDIVISION	107	197	202
	SUM OF SQUARES	DEG. FREEDOM	MEAN SQUARE
TOTAL	22.057	505	--
SYSTEMATIC	10.980	2	5.490
RESIDUAL	11.078	503	0.022

CALCULATED F	F AT 5% LEVEL	F AT 1% LEVEL
249.27	3.01	4.65

TABLE IV: ONE-WAY AOV STATISTICS FOR SPEED OF MOVEMENT

	SM≤6KT	6KT <SM≤13KT	SM>13KT
MEAN	0.409	0.405	0.485
VARIANCE	0.044	0.043	0.046
STD. DEV.	0.209	0.206	0.214
NUMBER IN SUBDIVISION	155	300	51
TOTAL	22.057	505	--
SYSTEMATIC	0.287	2	0.144
RESIDUAL	21.771	503	0.043

CALCUATED F	F AT 5% LEVEL	F AT 1% LEVEL
3.31	3.01	4.65

TABLE V: ONE-WAY AOV STATISTICS FOR DIRECTION OF MOVEMENT

	WESTWARD MOVING	NORTHWARD AND EASTWARD MOVING
MEAN	0.392	0.477
VARIANCE	0.041	0.047
STD. DEV.	0.202	0.217
NUMBER IN SUBDIVISION	376	130

	SUM OF SQUARES	DEG. FREEDOM	MEAN SQUARE
TOTAL	22.057	505	--
SYSTEMATIC	0.689	1	0.689
RESIDUAL	21.369	504	0.042

CALCULATED F	F AT 5% LEVEL	F AT 1% LEVEL
16.25	3.86	6.69

TABLE VI: ONE-WAY AOV STATISTICS FOR LATITUDE

	20°N AND SOUTHWARD	NORTH OF 20°N
MEAN	0.381	0.512
VARIANCE	0.041	0.040
STD. DEV.	0.202	0.201
NUMBER IN SUBDIVISION	378	128

	SUM OF SQUARES	DEG. FREEDOM	MEAN SQUARE
TOTAL	22.057	505	--
SYSTEMATIC	1.643	1	1.643
RESIDUAL	20.415	504	0.041

CALCULATED F	F AT 5% LEVEL	F AT 1% LEVEL
40.56	3.86	6.69

TABLE VII: ONE-WAY AOV STATISTICS FOR LONGITUDE

	130°E AND EASTWARD	WEST OF 130°E
MEAN	0.383	0.457
VARIANCE	0.043	0.041
STD. DEV.	0.208	0.202
NUMBER IN SUBDIVISION	292	214

	SUM OF SQUARES	DEG. FREEDOM	MEAN SQUARE
TOTAL	22.057	505	--
SYSTEMATIC	0.689	1	0.689
RESIDUAL	21.369	504	0.042

CALCULATED F	F AT 5% LEVEL	F AT 1% LEVEL
16.24	3.86	6.69

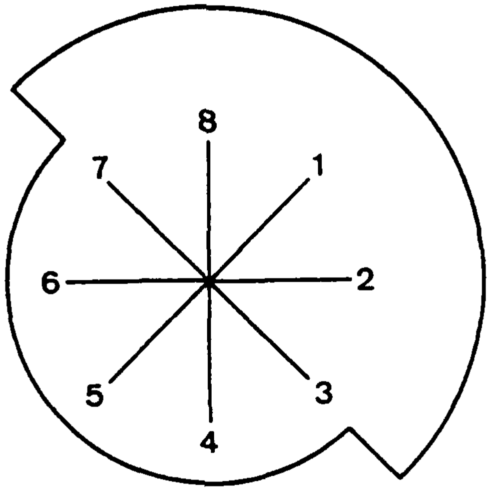
TABLE VIII: FIVE-WAY AOV STATISTICS FOR ALL FIVE PARAMETERS

	SUM OF SQRS.	DEG. F.	MEAN SQR.	CALC. F	TABULAR F 5%	1%
TOTAL	22.057	505	- -	- -	--	--
WIND SPD.	10.980	2	5.490	351.92	3.01	4.65
SPD. MVT.	0.287	2	0.144	9.20	3.01	4.65
DIR. MVT	0.689	1	0.689	44.17	3.86	6.69
LAT.	1.643	1	1.643	105.32	3.86	6.69
LONG.	0.689	1	0.689	44.17	3.86	6.69
RESIDUAL	7.769	498	0.016	--	--	--

NOTE: Values for Dir. Mvt. and Long. are identical because of rounding off.

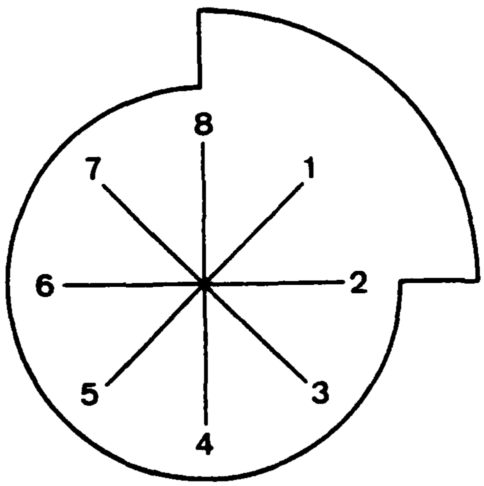
Figure 1: 30 KT WIND RADIUS EXAMPLES

30KT RADIUS:200 N MI NORTHEAST SEMICIRCLE,
150 N MI ELSEWHERE



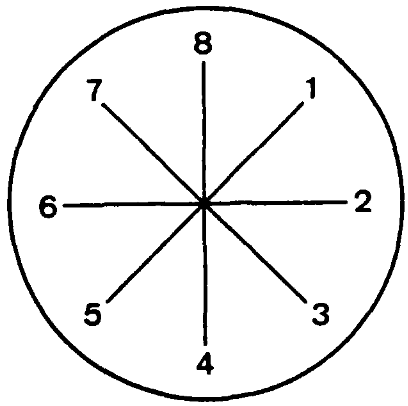
CODE: 3201S15

30KT RADIUS:200 N MI NORTHEAST QUADRANT,
150 N MI ELSEWHERE



CODE: 3201Q15

30 KT RADIUS:150 N MI ALL
QUADRANTS



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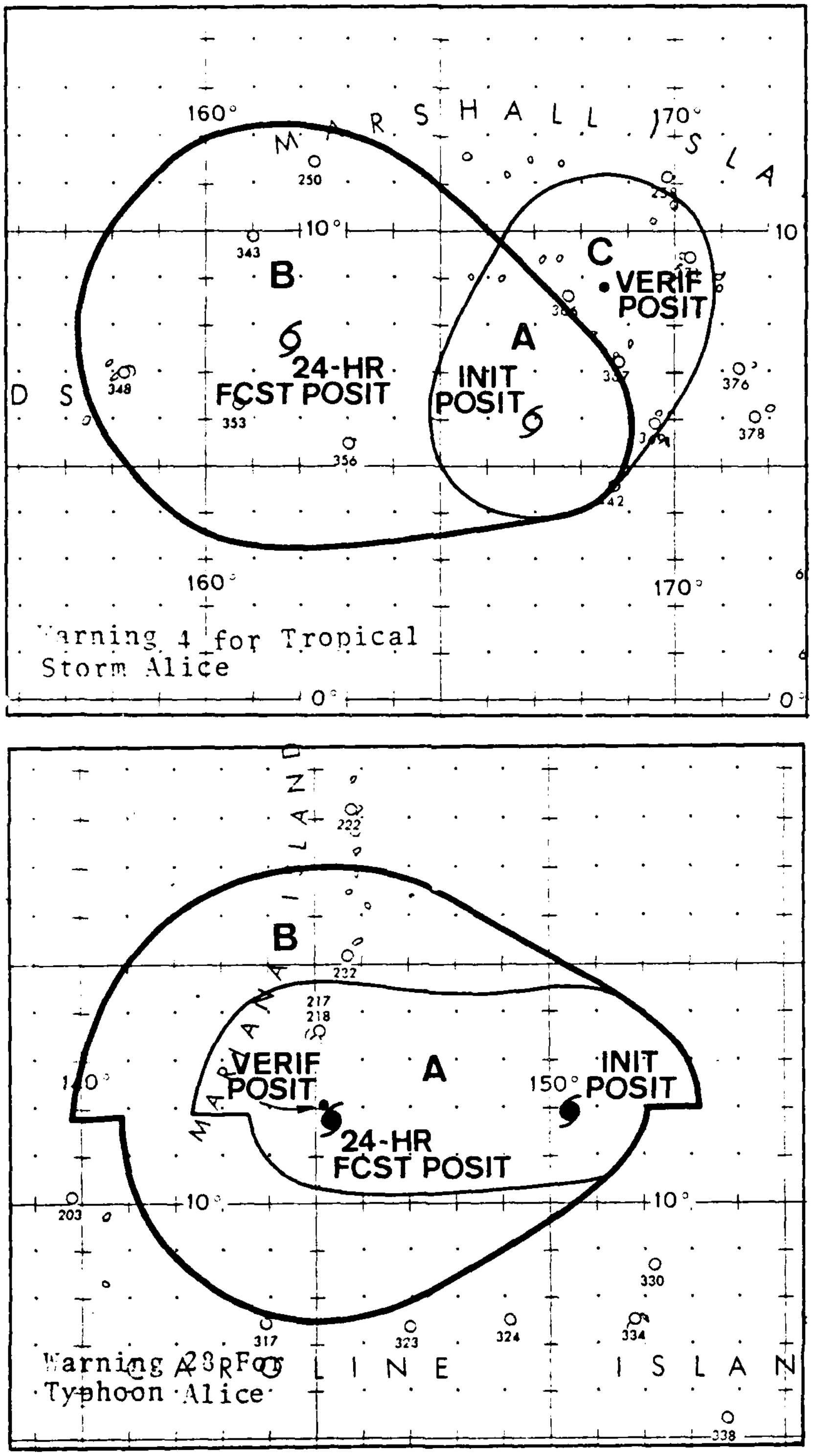

Figure 2: Field Plotted 30-KT Danger Area and Verification Area for Warnings 4 and 24 of Tropical Cyclone Alice (For descriptions of area see text)

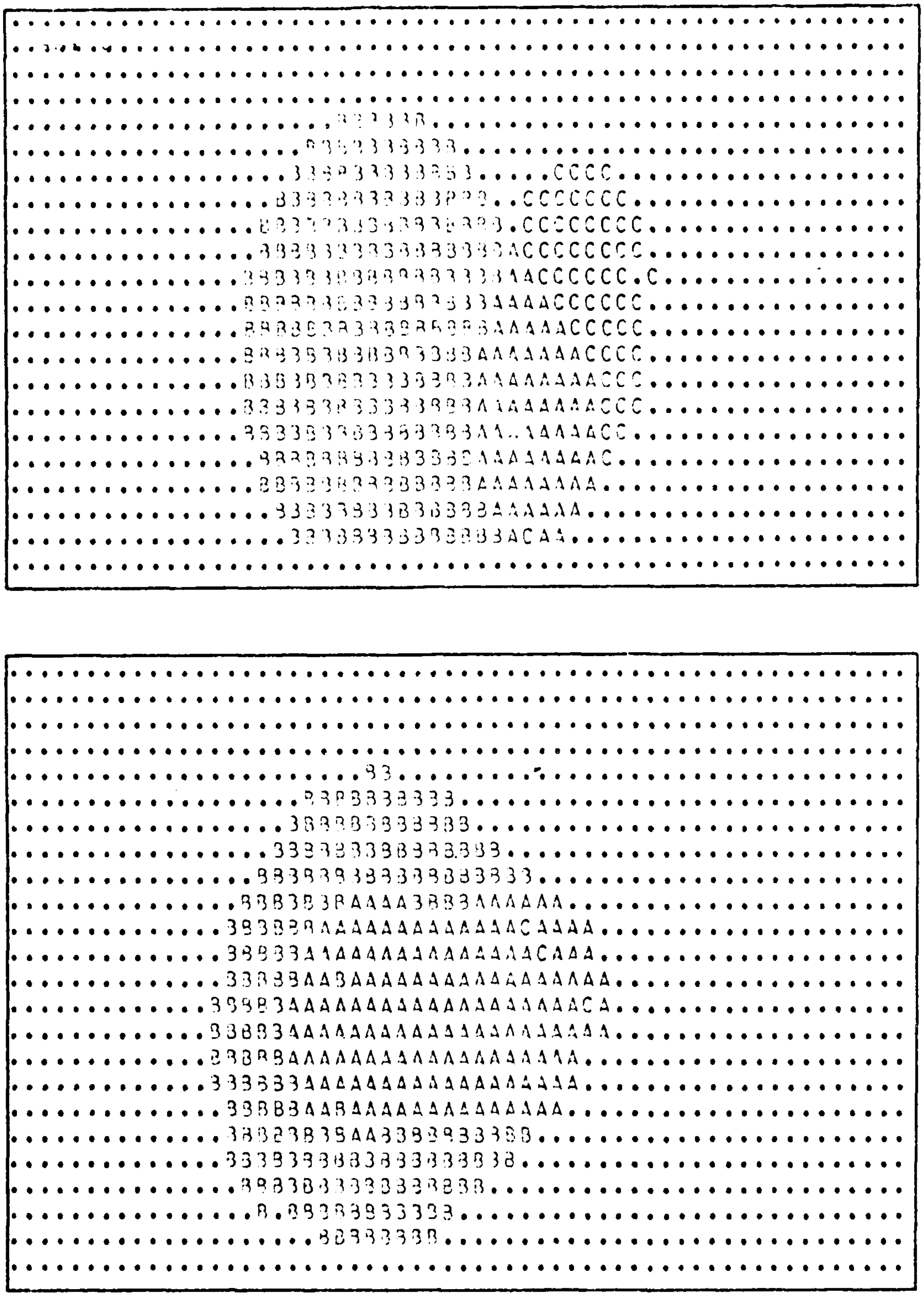

Figure 3: Computer Plotted 30-kt Danger Area and Verification Area

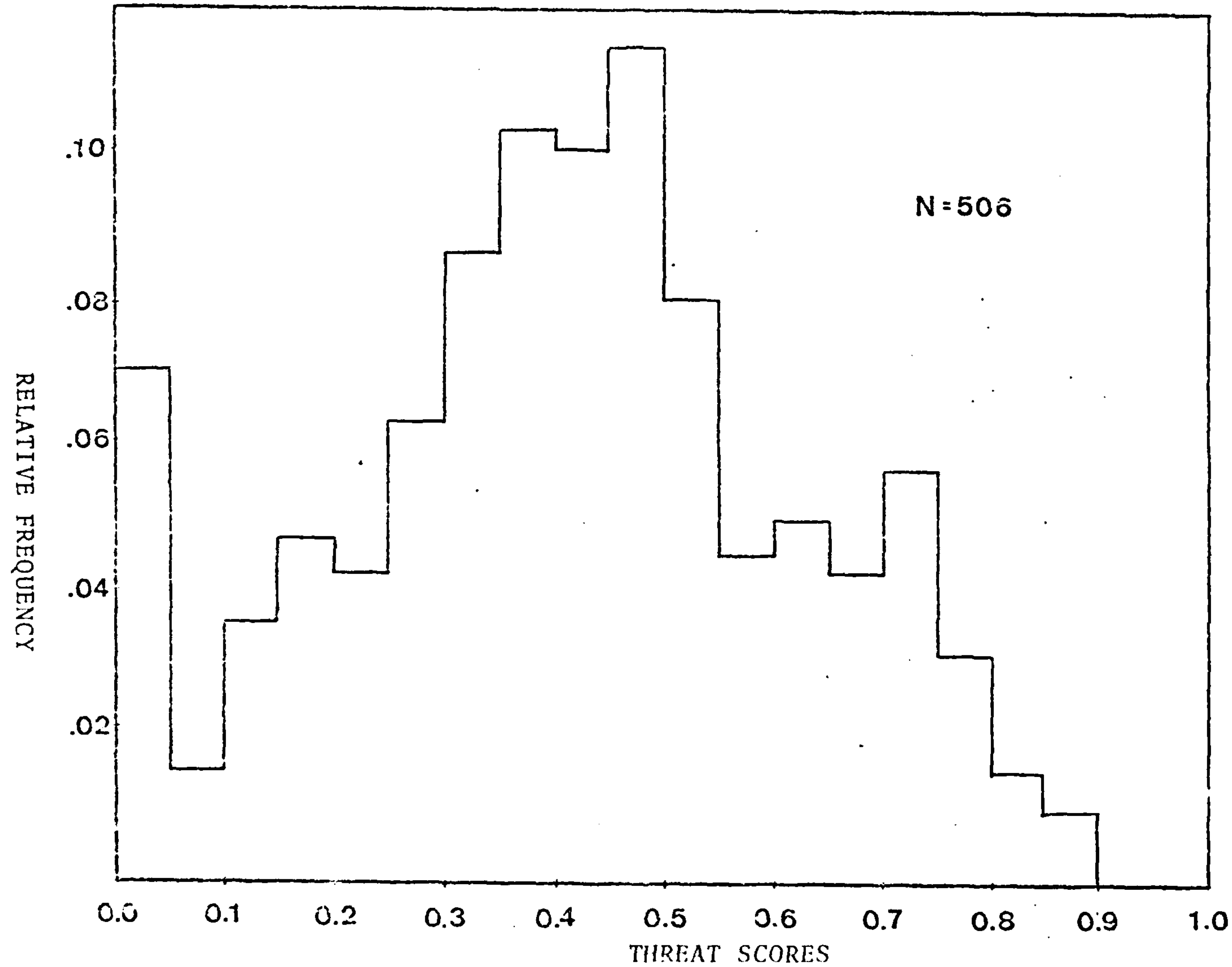

Figure 4: Frequency Distribution of Threat Score Values For All Warnings

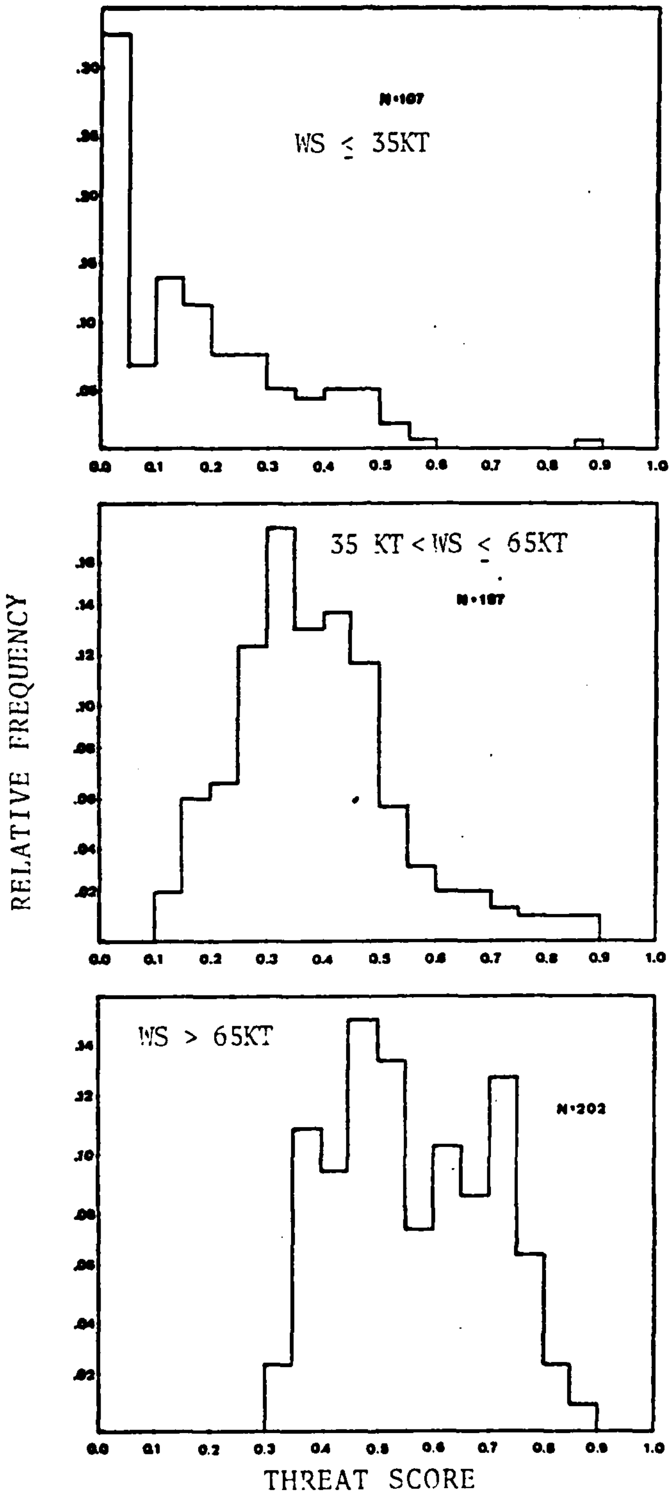

Figure 5: Frequency Distributions of Threat Score Values for Wind Speed Subdivisions

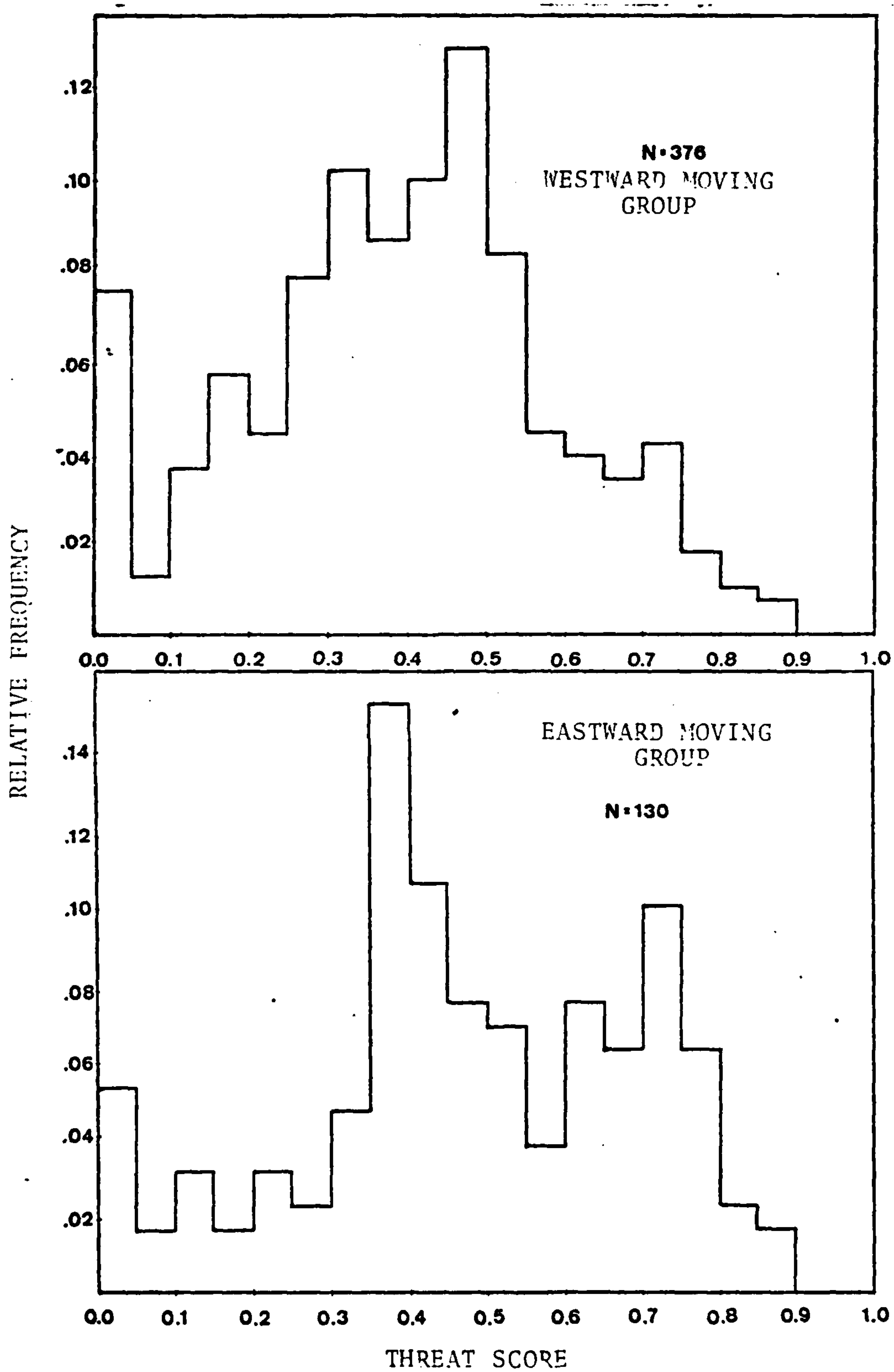

Figure 6: Frequency Distributions of Threat Score Values for Direction of Movement Subdivisions

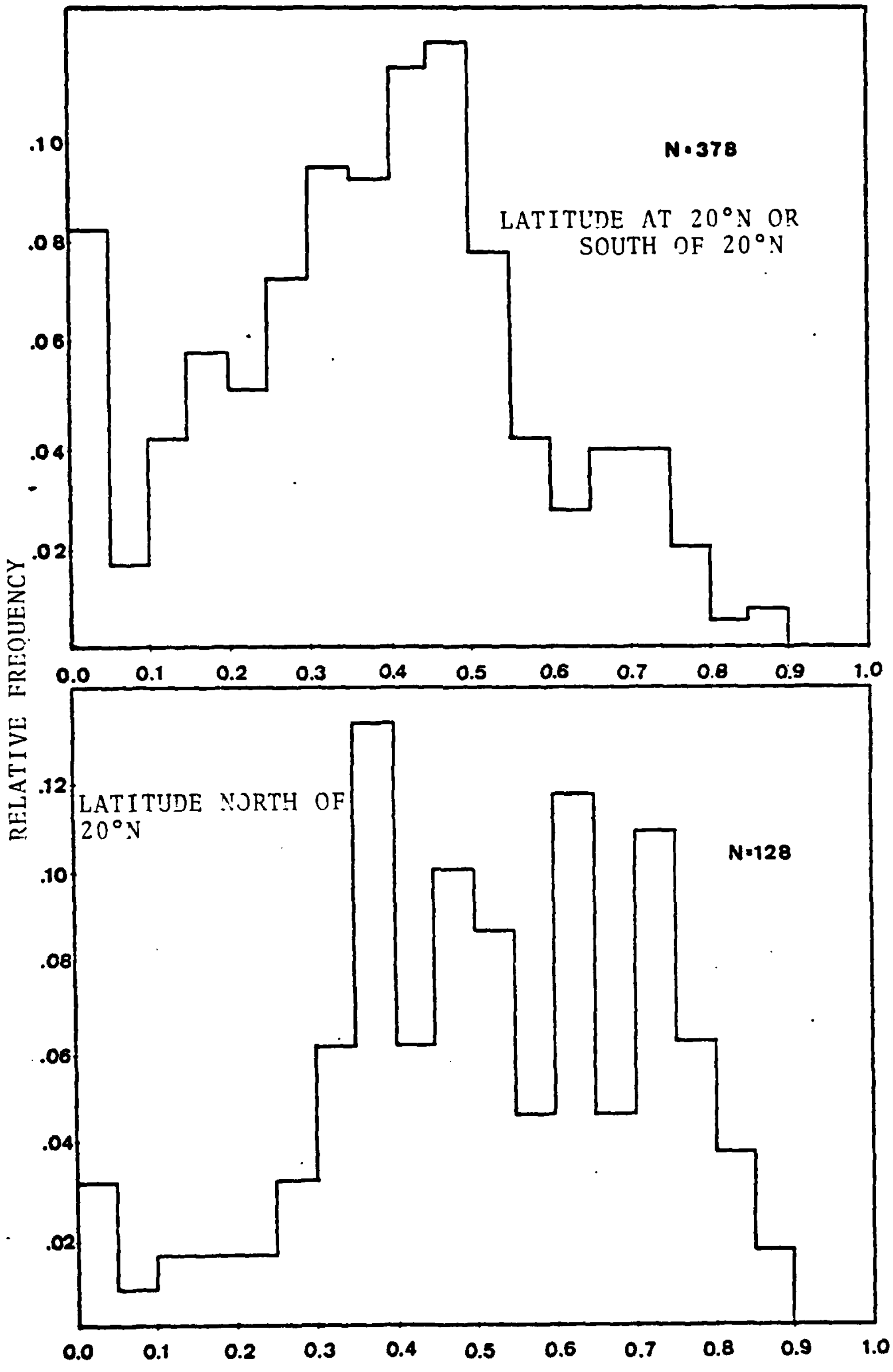

Figure 7: Frequency Distributions of Threat Score Values for Latitude Subdivisions

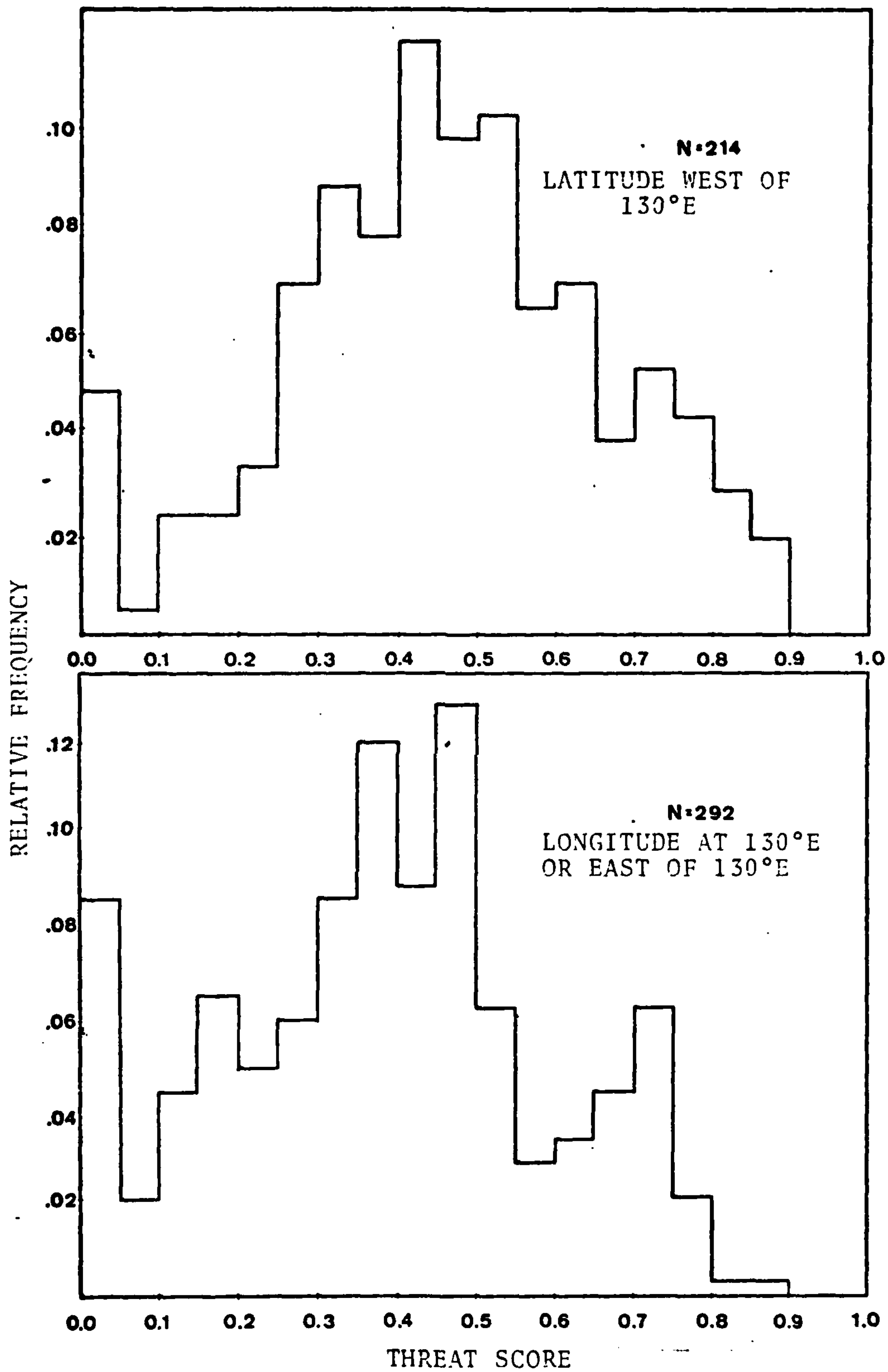

Figure 8: Frequency Distributions of Threat Score Values for Longitude Subdivisions

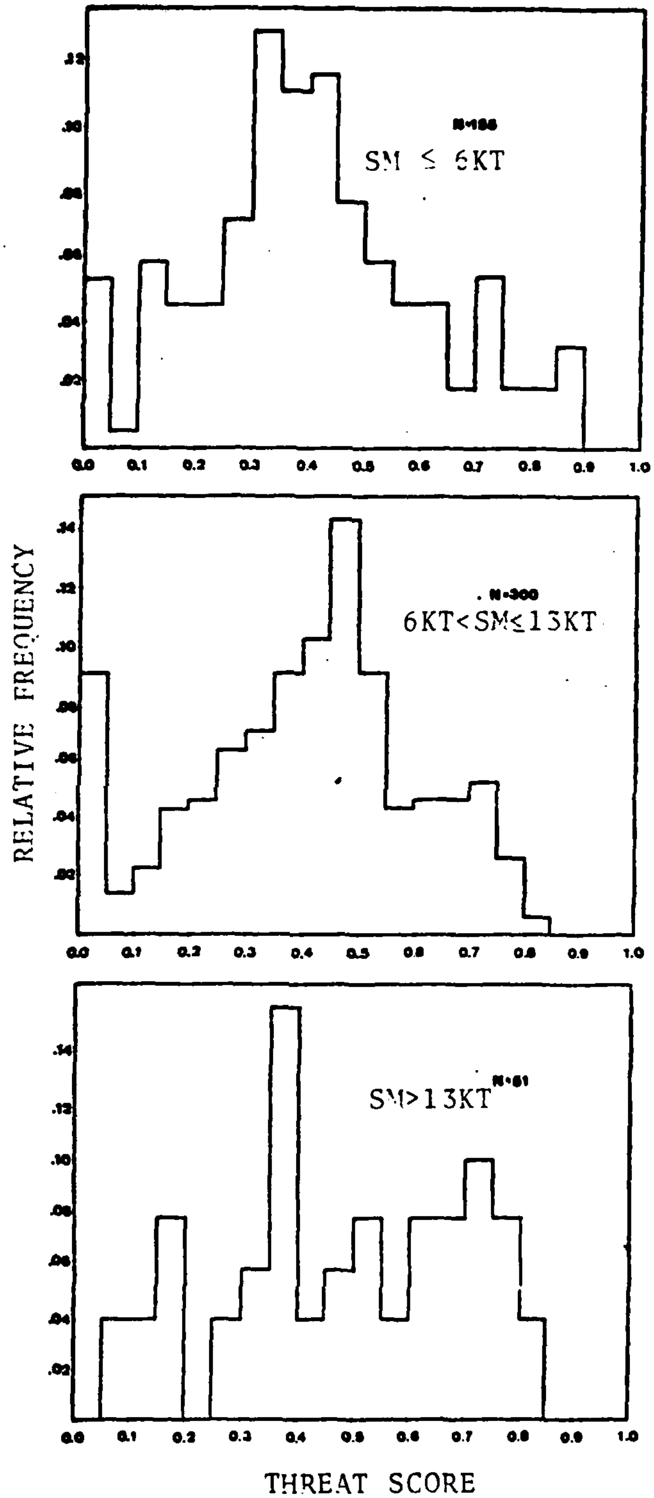

Figure 9: Frequency Distributions of Threat Score Values for Speed of Movement Subdivisions

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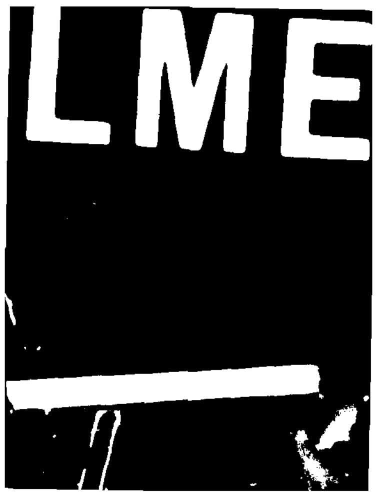
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